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**APPLICATION
FOR
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LETTERS PATENT**

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FOR: METHOD AND SYSTEM FOR DIGITAL
PRINTING BY DENSITY SCHEDULING

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METHOD AND SYSTEM FOR DIGITAL PRINTING BY DENSITY SCHEDULING

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention generally relates to method and system for digital printing, and more particularly to a method and system for digital printing, mostly addressed at printing images, which exploit better the two-dimensional aspect of images than error diffusion methods, and take much more account of the image than dithering methods.

Description of the Related Art

10 Most printers today can print in only a limited number of colors. Digital half-toning is a technique for printing a picture (or more generally displaying it on some two-dimensional medium) using small dots with a limited number of colors such that it appears to consist of many colors when viewed from a proper distance. For example, a picture of black and white dots can appear to display gray colors when viewed from some distance.

15 The fastest and most commonly used methods for digital half-toning are dithering

algorithms which use threshold arrays (i.e., also called dither matrices or dither masks).

The principle of this conventional method, as illustrated by Figure 1, is well known. The method allows to associate a matrix N of discrete values at 13 (typically "0" or "1", where "1" means a pixel is printed, and a "0" means nothing is printed) to an image I at 11 using a dithering mask 12 (i.e., a usually smaller matrix of threshold values). Various masks can be devised, according to the needs of precise applications, and several methods to devise masks with good performance have been disclosed (e.g., see U.S. Patent No. 5,111,310 to Parker et al., U.S. Patent No. 5,917,951 to Thompson et al., and U.S. Patent No. 6,025,930 to Thompson et al., each incorporated herein by reference).

However, instead of a dithering mask, one can also use other half-toning algorithms such as an error diffusion algorithm.

Before defining this class of techniques, it is noted that when using dithering, one could treat each pixel at any stage of the process, or treat a lot of the pixels in parallel, as the printing decision at each pixel (i.e., to print or not to print at that place) does not depend of the decision at any other point. In practice, one treats the pixels one-by-one, line-by-line, but this is just a matter of practicality, not a need of the method.

To the contrary, error diffusion is rasterization-dependent. That is, one can choose an order in which the pixels will be dealt with, e.g., line-by-line going down the page, and from left to right on each line. Once this order is chosen, before making a printing decision at pixel (i, j) (i.e., choosing which color(s) will be printed at that pixel, if any), one modifies the input at (i, j) by weighted errors made previously in the neighborhood, and computes a new error as the difference between the modified input and the printing decision.

Dithering masks as well as error diffusion can be easily adapted to use more than two possible outputs per pixel (i.e., several levels of gray instead of just black and white). In such a case, one then speaks of multi-tone printers (with a digital printer then referring to black and white pixels only). Also, all these techniques, can be easily adapted to color printing. That is, both adaptation to multi-tone and to color (i.e., digital or multi-tone color) are well known by one versed in the art of digital printing.

A well-known difficulty associated with dithering for a color image is linked to the fact that shifts on the paper, or the printing guns, may occur between different color components, which is known to create undesirable moiré patterns. This problem is usually corrected by using different masks in the various color planes.

Most of these techniques are reviewed in the book *Digital Halftoning*, MIT Press, Cambridge, MA (1987) by R. Ulichney, which is a general reference for digital half-toning in black and white. Regarding color, "Optical Color technology for electronic imaging devices" by Kang, Henry R. (Bellingham, Wash., USA: SPIE Optical, 1997) is a general reference for color digital printing.

Other, more global, and very much more time-consuming, methods have been proposed to perform digital half-toning, such as the use of neural networks or global optimization.

Thus, it is easy to understand why dithering works well for a uniform grey input. To the contrary, one can easily exhibit examples of images whose rendering by digital printing would be arbitrarily bad if using a dithering mask. This is because dithering only considers one pixel at a time. The reasonable results one obtains in practice for a natural image, such as pictures of natural scenes, are linked to the fact that, in general, such pictures are quite smooth. For

purposes of the present invention, "smooth" refers to a generally slow variation of the output from a pixel to the neighboring ones. Some poor cases are nevertheless commonly encountered.

Error diffusion avoids this problem to some extent, but suffers from the fact that it is attached to an arbitrary raster choice which by nature, destroys the fundamental 2-dimensional nature of images. More sophisticated methods which aim at global optimization in some sense are very slow.

SUMMARY OF THE INVENTION

In view of the foregoing and other problems, disadvantages, and drawbacks of the conventional methods and structures, an object of the present invention is to provide a method and system which is much faster than the search of global optimum, but which still can deal with the 2-dimensional aspect of the images.

In a first aspect, a method (and system) of digital printing includes forming a sequence of matrices P_k with entries 0 or 1 where a 1 at some entry in some P_k represents that this pixel will be printed at stage k , constructing as sequences of matrices I_k with entries in $[0, 1]$, so that $I_0 = I$, determining, when considering all pixels, a next pixel having a largest weight indicating that the next pixel is to be printed first, printing the pixel, and determining for each pixel of the remaining ones of pixels of the plurality of pixels a printing order of the remaining pixels such that subsequent pixels of the remaining ones of pixels of the plurality of pixels having a largest weight among the remaining pixels, are subsequently printed.

In a second aspect, a method (and system) of printing includes forming a matrix of pixels, determining an order of printing of the pixels, the determining including finding a weight of the pixels and printing a pixel having a highest weight, and reordering the remaining pixels and printing a pixel having the greatest weight of the remaining pixels until all pixels have been printed.

Further, a program storage medium is provided for storing program steps of the inventive methods.

With the unique and unobvious features of the present invention, a method and system are provided which are much faster than the search of global optimum, but which still can deal with the 2-dimensional aspect of the images without treating each pixel independently of its neighbors.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

Figure 1 illustrates the use of dither masks for half-toning, according to conventional methods;

Figure 2 shows a flow diagram which represents an exemplary method 200 of implementing the present invention;

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Figure 3 shows the structure of weights in a neighborhood $V(i, j)$ for a preferred embodiment of the present invention;

Figure 4 illustrates an exemplary hardware/information handling system 400 for incorporating the present invention therein; and

FIG. 5 illustrates a signal bearing medium 500 (i.e., storage medium) for storing steps of a program of a method according to the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE PRESENT INVENTION

Turning to Figures 2-5, a detailed description of a preferred embodiment according to the present invention will be described.

Prior to describing the preferred embodiment of the present invention and to make the description more precise, some notations will be introduced. Below, considered in detail is the case of digital printing with black and white dots of greyscale images. Other cases such as multi-tone and color will be discussed later.

The original image will be denoted as the matrix $I = \{I(i, j)\}$, where $1 \leq i \leq \text{Himage}$ and $1 \leq j \leq \text{Vimage}$. Each element $I(i, j)$ of I is a real number between 0 and 1, where 0 means "white" and 1 means "black".

The set of pixels to be printed after half-toning will be encoded in the matrix $P = \{P(i, j)\}$, where $1 \leq i \leq \text{Himage}$ and $1 \leq j \leq \text{Vimage}$ (i.e., this notation represents "horizontal" and

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“vertical” coordinates of the image). Each element $P(i, j)$ of P is either 0 or 1, where again “0” means “white” and “1” means “black”. It will be convenient to understand P as obtained from the constant 0 matrix by replacing as many 0s by 1s as needed to represent I .

Given an Himage-by-Vimage matrix M with entries in $[0, 1]$, some neighborhood $V(i, j, M)$ is chosen for each (i, j) , whose shape and size may either depend or not depend on (i, j) , and a set of weights associated to all pixels in $V(i, j, M)$. Then, $W(i, j, M)$ stands for the weighted average of the elements of M in $V(i, j, M)$.

Then, set $\text{GreyTotal} = \sum_{i,j} I(i,j)$.

Hereinbelow and referring to Figure 2, a method (algorithm) 200 is described which constructs a sequence of matrices P_k with entries 0 or 1, the last one being the matrix P preferably sought by the present invention. In the process, there will be constructed sequences of matrices I_k with entries in $[0,1]$, so that $I_0 = I$.

INITIALIZATION:

At step 201, first initialization is performed. That is, set $k = 0$ and define P_0 as the constant Himage-by-Vimage zero matrix.

LOOP:

In step 202, replace k by $k+1$ (i.e., as usual in languages such as FORTRAN, k now stands for what would have been $k+1$ before Step 1) and so forth for each iteration, and in step

203 set $I_k = I_{k-1}$, $P_k = P_{k-1}$.

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In step 204, determine whether there has been a change in $V(i, j, M_k)$. In steps 205 and 206, compute all $W(i, j, I_k)$ (weighted average) not computed so far and set $W(i, j, I_k) = W(i, j, I_{k-1})$ if $W(i, j, I_k)$ is not computed again (i.e., when $k = 1$, one computes them all, and for $k > 1$, one computes those which have been modified at the previous iteration).

5 In step 207, order all $W(i, j, I_k)$ by decreasing order, and in step 208 call $\text{Max}(k)$ the bigger value of all $W(i, j, I_k)$ s.

In step 209, it is determined whether $W(i, j, I_k) = \text{Max}(k)$.

For all pairs (i, j) such that $W(i, j, I_k) = \text{Max}(k)$ (i.e., a YES" in step 209), then in step 210, replace $P_k(i, j) = 0$ with $P_k(i, j) = 1$ in P_k , and $I_k(i, j) = I(i, j)$ with $I_k(i, j) = I(i, j) - 1$ in I_k . If a "NO" results in step 209, then the process loops to step 211 in which nothing at (i, j) is changed.

The process continues to step 212. In step 212, compute $\text{GreyTotal}(k) = \sum_{i,j} P_k(i, j)$.

Then, if $\text{GreyTotal}(k) < \text{GreyTotal}$ as determined in step 213, then the process loops to go to step 202 for the next iteration.

Conversely, if $\text{GreyTotal} \leq \text{GreyTotal}(k)$ as determined in step 214, and

15 $|\text{GreyTotal} - \text{GreyTotal}(k)| < |\text{GreyTotal} - \text{GreyTotal}(k-1)|$ as determined in step 215, then in step 216 set $P = P_k$.

Alternatively, if $\text{GreyTotal} \leq \text{GreyTotal}(k)$ as determined in step 214, and

$|\text{GreyTotal} - \text{GreyTotal}(k)| \geq |\text{GreyTotal} - \text{GreyTotal}(k-1)|$ as determined in step 215, then in step 217, set $P = P_{k-1}$. Thereafter, the process ends.

Of course, as would be known by one of ordinary skill in the art taking the present application as a whole, step 202 can easily be modified to vary the total number of black dots being printed, for instance to take account of the actual size of printed dots, compensate for originals which are too clear or too dark, just for a matter of taste, etc.

5 To apply this method with a multi-tone printer, one prints the lightest grey darker than $\text{Max}(k)$ (instead of necessarily a black dot in one bit per pixel printers), and replaces

$$I_k(i, j) = I(i, j) - 1$$

by

$$I_k(i, j) = I(i, j) - \text{"multibit grey level being printed"}$$

10 in steps 209-211 above.

To apply this method to color images, the image I is decomposed as usual in the color planes accessible to the printer (i.e., Cyan, Magenta, and Yellow, or Cyan, Magenta, Yellow, and Black) and then the method is used, as described above, in each plane. Then, in each color plane, either one bit or multi-tone printing can be accommodated readily.

15 The invention can further be adapted to accommodate for the fact that some printers (e.g., such as some laser printers) require dark pixels to be grouped together, forming so-called half-tone dots, to compensate for isolated pixels that do not print in a predictable and trustable way.

This accommodation is achieved by making the weights in $V(i, j, M)$ depend also on what is printed at (i, j) , for instance to favor printing near a pixel already designed to be printed. For
20 instance, near a pixel already designed to be printed, the sum of the weights in $V(i, j)$ may be greater than one, and otherwise may be smaller than one.

Thus, with the unique and unobvious features of the present invention, the tradeoff between performance and time required is optimized in that the time required by the inventive method, which may be greater than that for the conventional dither etc. techniques, is much smaller than for global optimization and other global methods. Conversely, the performance is much better than for the conventional dither etc. techniques.

Figure 4 illustrates a typical hardware configuration of an information handling/computer system in accordance with the invention and which preferably has at least one processor or central processing unit (CPU) 411.

The CPUs 411 are interconnected via a system bus 412 to a random access memory (RAM) 414, read-only memory (ROM) 416, input/output (I/O) adapter 418 (for connecting peripheral devices such as disk units 421 and tape drives 440 to the bus 412), user interface adapter 422 (for connecting a keyboard 424, mouse 426, speaker 428, microphone 432, and/or other user interface device to the bus 412), a communication adapter 434 for connecting an information handling system to a data processing network, the Internet, an Intranet, a personal area network (PAN), etc., and a display adapter 436 for connecting the bus 412 to a display device 438 and/or printer 439. As mentioned above, the printer 439 may be a digital printer or the like.

In addition to the hardware/software environment described above, a different aspect of the invention includes a computer-implemented method for performing the above method. As an example, this method may be implemented in the particular environment discussed above.

Such a method may be implemented, for example, by operating a computer, as embodied by a digital data processing apparatus, to execute a sequence of machine-readable instructions. These instructions may reside in various types of signal-bearing media.

Thus, this aspect of the present invention is directed to a programmed product,
5 comprising signal-bearing media tangibly embodying a program of machine-readable instructions executable by a digital data processor incorporating the CPU 411 and hardware above, to perform the method of the invention.

This signal-bearing media may include, for example, a RAM contained within the CPU 411, as represented by the fast-access storage for example. Alternatively, the instructions may be
10 contained in another signal-bearing media, such as a magnetic data storage diskette 500 (Figure 6), directly or indirectly accessible by the CPU 411.

Whether contained in the diskette 500, the computer/CPU 411, or elsewhere, the instructions may be stored on a variety of machine-readable data storage media, such as DASD storage (e.g., a conventional "hard drive" or a RAID array), magnetic tape, electronic read-only
15 memory (e.g., ROM, EPROM, or EEPROM), an optical storage device (e.g. CD-ROM, WORM, DVD, digital optical tape, etc.), paper "punch" cards, or other suitable signal-bearing media including transmission media such as digital and analog and communication links and wireless. In an illustrative embodiment of the invention, the machine-readable instructions may comprise software object code, compiled from a language such as "C", etc.

20 With the unique and unobvious aspects of the present invention, a method and system are provided in which the tradeoff between performance and time required is optimized in that the time required by the inventive method, which is greater than that for the conventional error

diffusion, dithering etc. techniques, is much smaller than for global optimization and other global methods. Conversely, the performance is much better than for the conventional error diffusion, dithering etc. techniques. Indeed, the invention exploits between the two-dimensional aspect of the images than error diffusion methods and takes much more account to the image that dithering methods. Thus, the inventive method and system are much faster than the search of global optimum, but can still cope with the 2-dimensional aspect of the images.

While a preferred embodiment of the present invention has been described above, it should be understood that it has been provided as an example only. Thus, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.